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Faience Beads from Grave M52 of the Majiayuan Cemetery, China: Materials and Technology

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Abstract: Majiayuan cemetery is located in northwest China, and dates from the late Warring States period (475 BCE to 221 BCE). Grave M52 was located in the west of the cemetery, a total of 297 pieces (sets) of funerary objects were unearthed from the grave. Among the various artifacts unearthed, several types of man-made faience beads were found, including blue and purple faience beads (of two sizes), tubular faience beads, eye beads and white beads, all used as personal adornments. In order to get a better understanding of different faience beads and to analyze their structure and material composition, several scientific methods were employed to enhance our understanding of the materials and craftsmanship, as well as providing valuable insights into the cultural exchanges of the period.
Keywords: Faience, eye bead, the Warring States Period

Introduction

Located in northwest China, Majiayuan cemetery dates from the late Warring States period to the Qin dynasty. The discovery of the cemetery provides important support for further exploration of the culture exchange [1]. Grave M52 was located in the west of the cemetery. The sacrificial animals are distributed across the west of the steps, as well as the lower part of the eastern wall, consisting of heads and hooves of cattle,

horses, and sheep. In order to comprehensively achieve relevant archaeological information and effectively preserve fragile artifacts, the wooden coffin was moved to the lab after conducting traditional archaeological recording and three-dimensional scanning. A total of 297 pieces (sets) of funerary objects were excavated from the coffin, made of materials such as gold, silver, copper, iron, tin, lead, turquoise, glass, and silicates, with silicate beads being the most abundant. The objects were mainly concentrated around the tomb occupant's head, neck, waist, feet, the right side of the femur, the outer side of the right tibia, and between the coffin's side panels. Based on the excavation locations, artifact decorations, and comparisons with items from other tombs in the cemetery, a comprehensive analysis of their attributes and functions enables the categorization of the excavated objects into three main types: chariot and horse ornaments, body adornments, and clothing accessories[2].Among the various artifacts unearthed, several types of man-made faience beads were found, including blue and purple faience beads (of two sizes), tubular faience beads, eye beads and white beads, all used as personal adornments. Although their quantity is limited, these beads are an important element of the tomb owner's body decoration.

Faience appeared in west Asia and Egypt from the late 5th millennium BCE to the early 4th millennium BCE. The manufacturing techniques spread from such regions to surrounding areas, via west Asia, central Asia, as well as China’s Xinjiang region and the Hexi Corridor, and then into the Central Plains since the Bronze Age [3] . Lead-barium silicate products consist of lead- barium glazed pottery, lead-barium faience, lead-barium glass and copper barium silicate pigment. Lead-barium faience from the Warring States period has been widely unearthed across the Yellow River and Yangtze River basins in China. These artifacts are exclusively small beads used as ornaments, comprising two types: plain tubular beads and eye beads [4]. Scientific research on these faience beads has mainly focused on shaping method and glazing method[5-6]. Previous studies indicate that the flux composition of faience is a key indicator for provenance. In west Asia and Egypt, early faience production utilized lime, natron, and soda-rich plant ash as fluxes[7]. The Alagou cemetery is located in Xinjiang, China, and has historically served as a key passage along the Tianshan route of the Silk Road, connecting the northern and southern parts of Xinjiang. Dating from the Warring States period to the Western Han dynasty, the site has yielded a large number of glass beads with different flux system, including plant-ash soda-lime glass, natron glass, potash glass, and lead-barium glass, representing nearly all major flux

compositional types[8]. The adoption of lead and barium as flux in glass/faience production was found exclusively in China since the same period[9-11].

Eye beads were characterized by eye-shaped motifs, originated in ancient Egypt around the 14th century BCE and were introduced to China in approximately the 5th century BCE. Following their introduction, artisans in the Chu state started producing local imitations, which led to increasingly diversified decorative patterns and shifts in usage, ultimately giving rise to products with distinct Chinese characteristics. From the mid-to-late Warring States period onward, such beads were widespread in different cultural regions in China. They were used as components of strung ornaments as in west Asia and north Africa, and could also be used as individual burial beads[12]. Given the complexity and variability of eye bead production techniques, imaging technologies are particularly effective for their investigation. X-ray CT analysis of the matrix, eye decorations, voids, and perforations of eye beads allows for the inference of their production process and sequence[13]. OCT (Optical Coherence Tomography) imaging can reveal whether the 'eye' sections of eye beads exhibit a layered structure, thereby indicating the use of a layering technique—a process in which molten glass is applied drop by drop onto a semi-molten glass matrix to form the eye decoration[14-15]. Studies of the Warring States eye beads unearthed in Hunan province showed three compositional systems—soda-lime, potash-lime, and lead-barium silicate glass[16-17]. In Henan province, apart from above types, lead-barium faience and potash-lime faience have also been found. The recipes and raw materials used for lead-barium glass during the Warring States and Han dynasties were notably diverse. The detection of lead and barium within typical Western soda-lime glass matrices suggests that glass remelting technology has existed by the Warring States and Han periods[18].

In order to get a better understanding of different beads and to analyze their structure and material composition, methods such as optical microscopy (OM), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS), Computed Tomography (CT) and Raman spectroscopy were employed. This study not only enhances our understanding of the materials and craftsmanship but also provides valuable insights into the cultural exchanges of the period.

Materials and Method

Materials

Different types of faience beads were excavated in grave M52, the plain purple and blue

beads were studied and reported [19]. In this paper, several types of faience beads (Fig.1) such as blue beads, tubular beads, eye beads and white beads were selected for study.

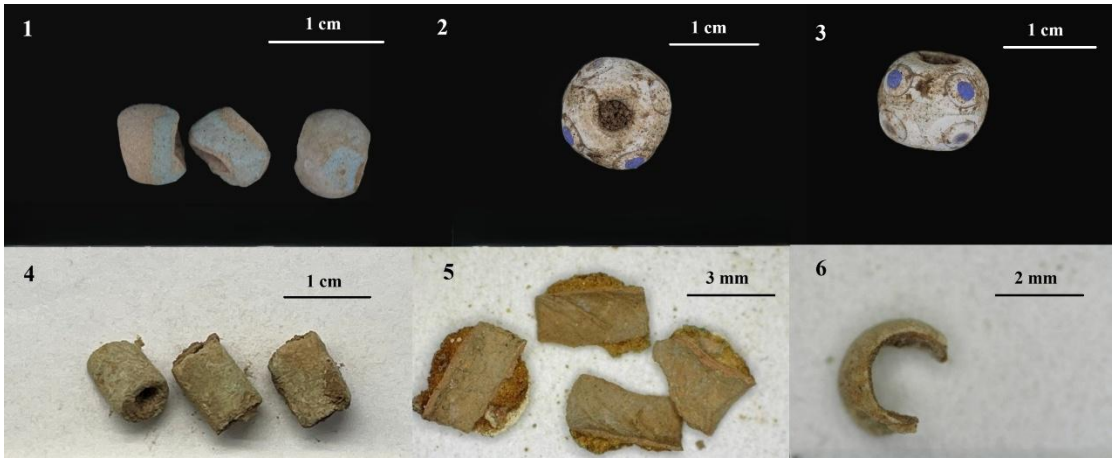


Fig.1 The faience beads excavated from M52

1: Blue beads, 2-3: Eye beads, 4: Tubular beads,

5: White beads-type A, 6: White beads-type B

The blue beads are spherical and centrally perforated. They exhibit slight size variation, with a diameter ranging from 6.9 to 7.2 mm, a height of 4.1–5.1 mm, and an aperture diameter of 2.9–3.3 mm. The bead surfaces retain traces of a blue glaze layer that is poorly adhered to the body and shows evidence of peeling. Two eye beads were unearthed near the left and right knees of the tomb occupant, respectively; one bead is intact and the other fragmented. These beads are spherical, white in color, and decorated with slightly protruding purple eyes. They are longitudinally perforated and measure 12.2 mm in diameter, 10.2 mm in height, and 2.7 mm in aperture diameter. The tubular beads are cylindrical and longitudinally perforated. They vary in size, with lengths ranging from 8.9 to 12.2 mm, outer diameters of 6–7 mm, and an aperture diameter of approximately 3.2 mm. Two types of white faience beads were identified. Type A white bead exhibits a distinct layered body–glaze structure, whereas Type B white bead lacks this feature. Both types occur in very limited quantities.

Methods

Microscopic analysis

The samples were observed under an Axio Scope A1 polarized microscope equipped with an ICCS optical system (Zeiss Ltd., Germany) and a VK-X250 three dimensional digital microscope (Keyence Corporation, Japan) at magnification levels of 50 to 200 times and 20 to 200 times, respectively. A Dino-lite AM7915MZT portable microscope, set to a magnification of 20x–200x, was employed for the observation of fragile beads.

SEM-EDS (scanning electron microscopy in combination with energy dispersive X-ray analysis)

Beads with full layer were selected, embedded by an inlaying machine (CitoVac, Struers Ltd., Denmark), and ground by a Tegramin-20 automatic grinding equipment (Struers Ltd., Denmark) to reach the surface of the samples. SEM-EDS analysis was conducted with a FEI Verios 4G SEM coupled with an Oxford X-max 20 EDS analyzer to obtain backscattered electron (BSE) images for phase and layered structure investigation. Samples were analyzed with a 20 kV acceleration voltage and 6.0 to 7.0 mm working distance. The samples were sputter coated with gold for the enhancing of conductivity prior to the test. Element characterization of each mineral/ area was achieved via EDS. The test at each spot/area was repeated at least three times to eliminate the error caused by inhomogeneous. To test the composition of each layer, a relatively homogeneous area covering as much as possible was selected as the test zone, thus ensuring data accuracy and representativeness.

Micro-Raman spectroscopy

A Renishaw inVia RM200 Raman spectrometer coupled with a microscope was used to characterize the minerals and compounds of the samples. Measurements were performed using an argon gas laser at 532 nm with a range 100 to 4000 cm^{-1}. Different color zones were selected for detection. The detection temperature was 25 °C, and the humidity was below 50%. The spectral resolution was 0.5 to 1 cm^{-1}, and the laser power was approximately 0.5 mW, thus ensuring good quality spectra. Samples were placed directly under the microscope to select interesting areas for detection. OriginPro 8.5 was used for spectra treatment.

Results and Discussion

Blue beads

Microscopic observation of the bead surface and cross-section reveals a greyish-brown body covered by a blue glaze layer (GLZ) (Fig. 2-1, 2-2). The GLZ is homogeneous and uniform in color. The perforations are straight but show slight variations in circularity (Fig. 2-5), suggesting that they were produced using a core-forming technique and shaped individually. Bubbles and spherical transparent granules are present along the perforation edges (Fig. 2-6) and on the surface of the GLZ (Fig. 2-3). Raman spectra identified these granules as quartz. Their formation is likely related to reactions between quartz particles in the GLZ and the surrounding flux during heating. Quartz grains with sharp edges, which have greater contact with the flux, are

preferentially consumed due to higher reaction activity. Because of a local excess of quartz, some particles remain partially unreacted and persist as spherical granules.

A clear boundary between the body and the GLZ is visible in cross-section (Fig. 2-4) and under polarized microscope (Fig. 2-7, 2-8), which is characteristic of the direct glazing method. CT slice images show straight perforation walls, further supporting the use of a cylindrical core in a core-forming process. The smooth and well-defined interface between the body and the GLZ (Fig. 2-9, 2-10) is consistent with this manufacturing technique. Backscattered electron (BSE) imaging by SEM (Fig. 2-11, 2-12) reveals a clearly defined microstructure with a distinct boundary between the GLZ and the body. An interaction layer (IAL), approximately 100 μm thick, is present between these two regions. Similar IAL structures have been reported in previous studies of faience beads [20–21] and are partially observed in Warring States period faience beads from China [9]. In contrast, the IAL was not detected in smaller round faience beads from grave M52 [19], suggesting that the morphologically similar beads within the same tomb may derive from different production sources.

Quartz grains within the IAL are intermediate in size between those in the GLZ and the body, retaining sharp, angular morphologies. The absence of clear reaction features suggests that their dimensions changed little during heating. This microstructure resembles the engobe layers observed in ancient ceramics [22]. The IAL may have functioned to regularize the bead surface, facilitating more uniform glaze application [23]. Quartz grains occur in both the GLZ and the body. The GLZ contains fewer and finer quartz grains and is largely vitrified, indicating exposure to higher effective heating temperatures and more complete reactions with the flux. In contrast, the body contains more abundant, coarser quartz grains with angular edges bound by an interparticle glassy phase, suggesting lower heating temperatures and incomplete flux reactions. The marked difference in grain size between the GLZ and the body implies separate preparation of raw materials, with the quartz used in the GLZ being more finely ground. Spherical voids observed within the GLZ are interpreted, in conjunction with microscopic observations, as cavities left by the detachment of partially reacted quartz granules. The spherical dark particles observed microscopically are therefore likely quartz grains that did not fully react with the flux.

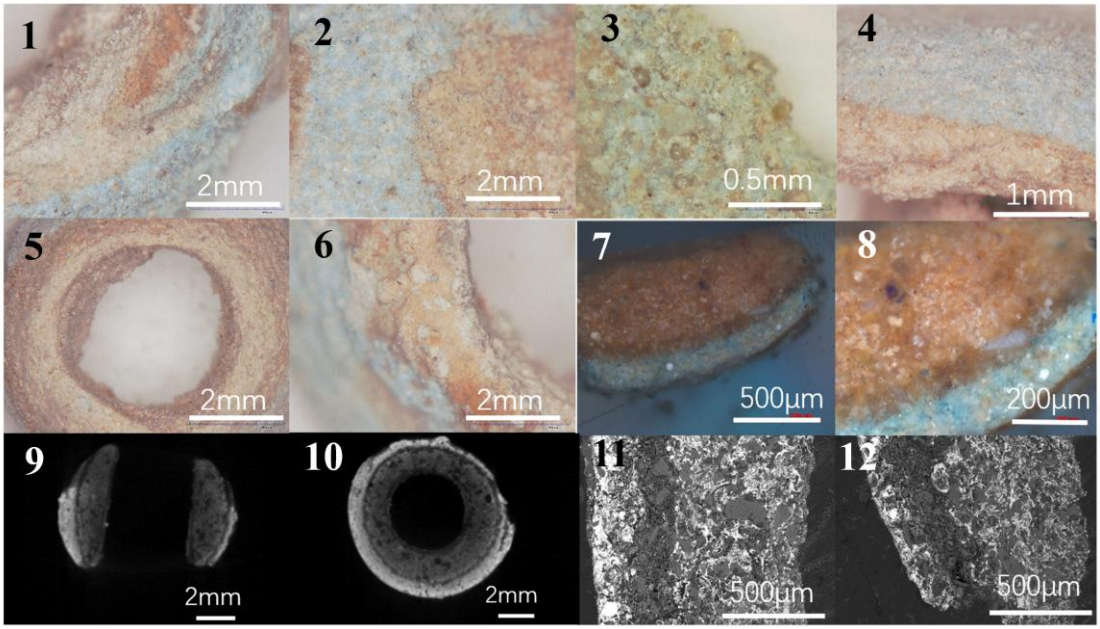


Fig.2 Microscopic analysis of blue beads

1-6 Surface of beads by microscope, 7-8 Cross section of the beads by microscope,

9-10 Photo by Industrial CT,11-12 Cross section of the beads by SEM

Compositional analysis by SEM (Tab. 1) indicate that the blue faience beads belong to the PbO–BaO–SiO_2 system. In the bead body, SiO_2 ranges from 44% to 73%, BaO averages approximately 1.8%, and PbO ranges from 11% to 26%. In contrast, the GLZ contains significantly lower SiO_2 (14–25%) and correspondingly higher PbO and BaO contents. This compositional contrast indicates separate preparation of body and glaze materials. The elevated PbO and BaO contents in the GLZ were likely introduced intentionally to enhance vitrification, while increased CuO served as a colorant. The IAL has a distinct composition (approximately 70% SiO_2, 1.7% BaO, 6.1% PbO, and 5.9% CuO) that differs from both the body and the GLZ, particularly in its lower PbO content. This suggests that the IAL may represent a separately applied interaction layer, although its precise function requires further investigation.

Tab. 1 Composition of blue faience beads by SEM-EDS (wt%)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	Fe_2O_3	CuO	BaO	PbO
Body-1	2.1	0.6	1.9	73.1	3.1	0.8	2.1	1.1	2.1	1.8	11.2
Body-2	4.1	0.6	1.7	44.5	8.5	1.5	4.1	1.8	5.4	1.9	25.9
IAL	5.4	0.7	2.1	70.0	3.3	1.5	2.1	1.3	5.9	1.7	6.1
GLZ	2.3	0.0	0.9	25.3	1.5	0.0	1.1	0.0	6.6	18.5	43.8
GLZ-2	2.8	0.4	0.9	21.7	6.6	0.3	1.6	0.0	8.7	19.8	37.1

Raman analysis of the white area of the bead body (Fig. 3a) shows absorption peaks at 460 and 1052 cm^{-1}, corresponding to quartz and lead sulfate. The blue region exhibits characteristic bands at 419, 460, 883, and 1097 cm^{-1}, attributable to Han blue (local man-made copper barium silicate pigment). The absorption band near 1097 cm^{-1} corresponds to the a_1g ν(Si–O) vibration, while the feature around 419 cm^{-1} is associated with a_1g bridging oxygen breathing modes [24]. Additional peaks observed in white crystalline areas at 419, 462, 980, and 1097 cm^{-1} are consistent with lead carbonate and quartz.

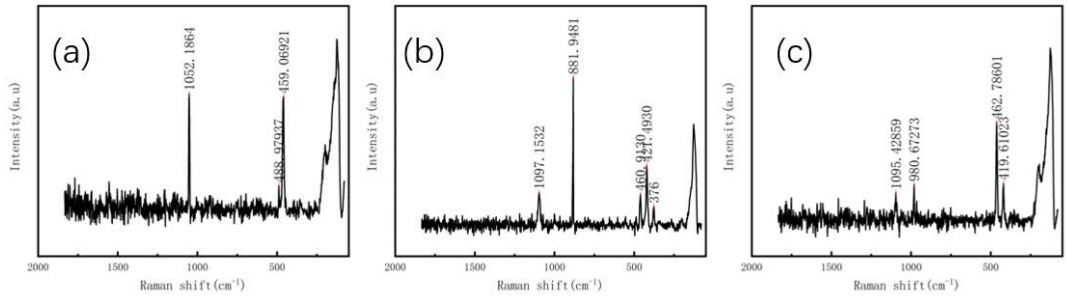


Fig. 3 Raman spectrum of blue bead (a) White area, (b) Blue area, (c) White crystal

Eyebeads

The eye beads are in poor condition and extremely fragile. Microscopic analysis reveals that eye bead features eight purple eyes, each outlined with a red circle. The dimensions of the eye bead are 12.2 mm in diameter, 2.7 mm in aperture diameter, and 10.2 mm in height. The purple circular pattern has a radius of 0.829 mm, while the outer red circle has a radius of 1.802 mm. Interestingly, at the center of each of the four eyes lies a green curvilinear rhombus, with side lengths of 3.453 mm and 2.963 mm. A green dividing line also runs between the upper and lower rows of eyes, passing through the two ends of each rhombus (Fig. 4-1). The eye consists of a red layer (0.08-0.219 mm) applied on the substrate, followed by a white layer (0.144-0.282 mm), and finally a surface layer, arranged from the inside outward (Fig. 4-2, 4-3). Most of the eye beads produced in early China feature multi circular eye patterns, usually consisting of three to five circles. In addition to the circular patterns, rhombus patterns are also formed through various combinations. It is rare for circular patterns and rhombus patterns to exist independently [12]. Observation of the internal surface of the fallen part shows some fluffy material distributed randomly (Fig. 4-4). Since only two eye beads were unearthed and they are extremely fragile, no further analysis was conducted on them.

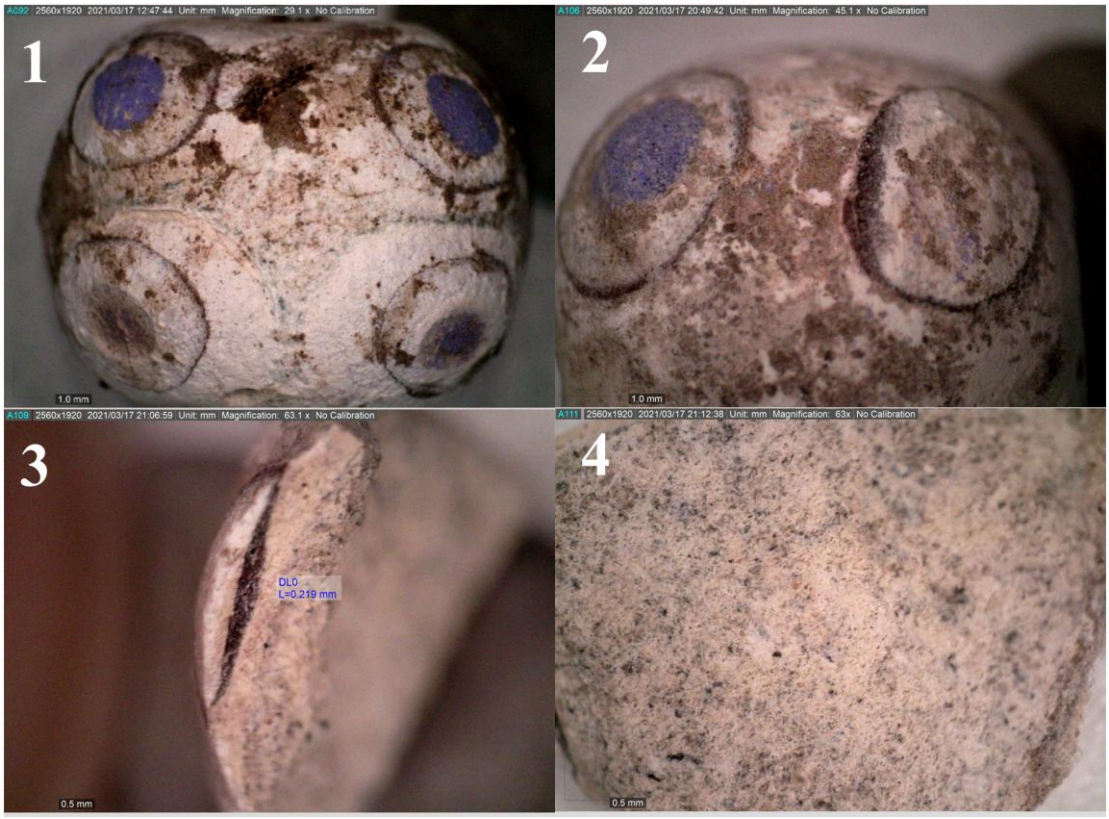


Fig.4 Microscopic analysis of eye beads

1-2: Surface of the eye bead, 3: Cross-section of the eye bead fallen part,

4: Internal surface of the fallen part

Tubular beads

The surface of the tubular faience bead is covered with a blue glaze layer, partially peeled off, and the body is greyish-yellow in color (Fig. 5-1). Textile residues were observed in the perforation, which are red and belong to a plain weave fabric (Fig. 5-2, 5-3). The boundary between the glaze layer and the body is indistinct, suggesting that the glazing technique may have employed the efflorescence method, with no significant interaction layer visible (Fig. 5-4, 5-5, 5-6). The body contains many quartz particles, with particle sizes ranging from 70 to 250 μm, and the quartz particles have sharp edges, indicating that the body was subjected to relatively low temperatures during the manufacturing process and had a limited reaction with the flux (Fig. 5-7). The structure of inner layer is dense, with localized inclusions of quartz particles. The perforation of the tubular bead is straight and smooth, suggesting it was made with a cylindrical core. The thickness of the faience tube is approximately 0.80 mm, and the glaze layer's thickness is about 0.10 mm. CT slices (Fig. 5-8, 5-9) reveal a straight perforation inner wall, characteristic of production using a cylindrical core, and no distinct boundary between the body and the glaze

layer is observed, further confirming that the bead was likely made by the efflorescence glazing method.

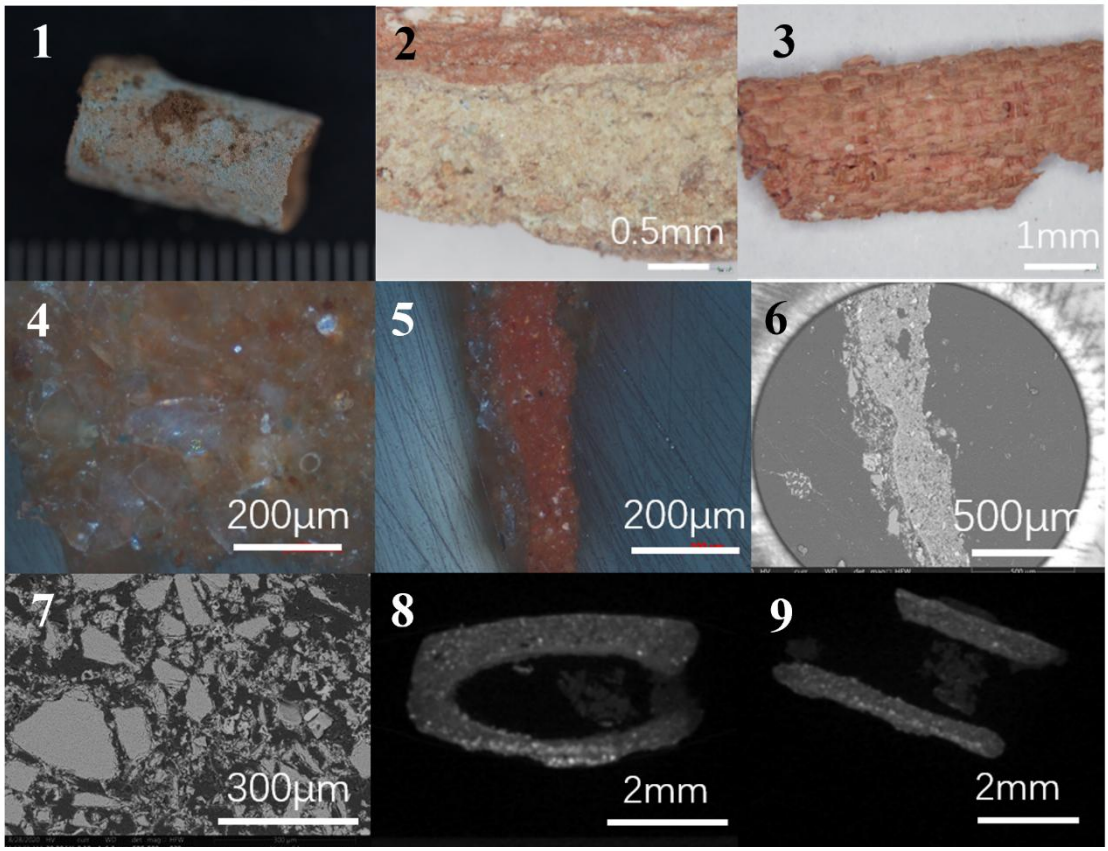


Fig.5 Microscopic analysis of tubular beads

1: Tubular bead, 2-3: Textile, 4-6 Cross section,

7: Image by SEM, 8-9: Image by industrial CT

The composition of tubular beads are shown as Tab. 2, indicate that the tubular faience beads belong to the PbO–BaO–SiO_2 system. The SiO_2 content ranges from 65% to 70%, BaO from 1.2% to 5.5%, PbO from 7% to 15%, and CuO from 1.8% to 4%. The Na_2O and K_2O contents are 1.0–1.5% and 0.4–1.2%, respectively, while CaO ranges from 0.4% to 1.5%, with MgO being nearly undetectable. Compared with the body, the surface exhibits higher concentrations of SiO_2, CuO, and BaO, whereas PbO is markedly lower. This is most likely attributable to weathering of the faience tube: lead to leaching results in Pb depletion and a relative enrichment of other major elements. In addition, the comparatively elevated CuO and BaO contents at the surface may be associated with the glazing process. Phosphorus was detected in the body of the faience tube but not on the surface, suggesting that plant ash may have been incorporated during body preparation. The inner layer of the tubular faience beads contains approximately 11% Al_2O_3, 50% SiO_2, 10.5% Fe_2O_3, 5.5% CaO, and

2.5% K_2O. This compositional profile is comparable to that of clay, indicating that the inner layer is most likely a product of fired clay.

Tab. 2 Composition of tubular faience beads by SEM-EDS (wt%)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	Fe_2O_3	CuO	BaO	PbO
Inner layer	2.6	3.0	11.0	59.3	2.2	0.9	2.5	5.5	10.5	2.5	0.0	0.0
Surface	1.5	0.0	1.3	78.7	0.0	0.0	0.4	0.5	0.5	3.8	5.5	7.8
Body-1	1.3	0.3	5.5	65.5	3.9	0.0	1.2	2.1	2.5	1.8	1.5	14.4
Body-2	1.1	0.4	3.6	68.1	3.5	0.0	1.0	1.9	2.1	2.1	1.2	14.9

Raman spectrum of tubular bead is shown as Fig. 6. The blue region exhibits Raman bands at 423, 555, 792, 989, and 1095 cm^{-1}, which are consistent with the characteristic peaks of Han blue. The white region shows a Raman band at 464 cm^{-1}, corresponding closely to the characteristic Raman peak of quartz.

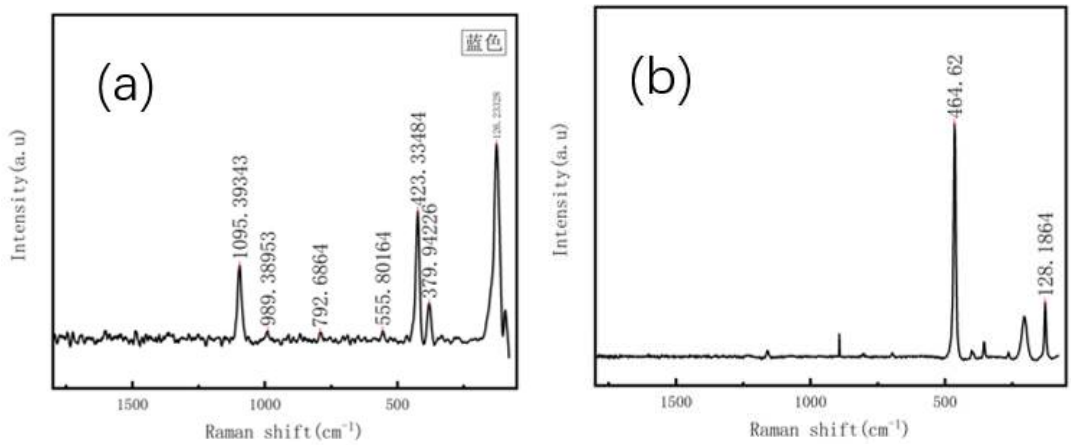


Fig.6 Raman spectrum of tubular beads (a) Blue region (b) White reigon

White beads

Few white beads (fragments) were unearthed in M52, they were divided into type A and type B according to the structure. Type A white beads are fragments, they consist of a greyish-white glaze layer, a body layer, and an inner layer (Fig. 7-1). The perforation walls are straight and smooth, representing typical characteristics of the core-forming technique. A clear boundary between the body and glaze indicates that the beads were produced using direct glazing. The glaze layer is dense, uniform in color, and relatively consistent in thickness. It is connected to the inner layer and encloses the body, while no glaze is observed on the inner layer. This suggests the following manufacturing sequence: the core and body were first shaped into a bead and allowed to dry; the bead was then coated or immersed in glaze; after drying, it was heating; finally, the core was removed/disappeared. To further investigate the microstructural characteristics of the faience beads, a fragment with full structure was embedded and

examined by polarized microscopy (Fig. 7-3). Distinct boundaries are visible between the glaze and the body, as well as between the body and the inner layer. The glaze layer is dense, with relatively few residual quartz particles that are small in size and lack sharp edges, indicating that the glaze experienced relatively high firing temperatures and reacted extensively with the flux. In contrast, the body contains abundant pores and residual quartz grains. The pores are predominantly ellipsoidal, and the quartz particles are larger with clearly rounded edges, suggesting that the body was subjected to elevated temperatures during firing and partially reacted with the flux to form a glassy phase. Numerous bubbles are observed both within the body and at the interface between the body and the inner layer (Fig. 7-2); these are likely related to reactions occurring during firing and will be discussed further following compositional analysis. Microscopic observations of Type B white faience beads show that they consist of an outer white bead layer and an inner layer, with a smooth and clearly defined boundary between them (Fig. 7-4, 7-5). The straight perforation indicates shaping by the core-forming technique. Due to long-term burial, the beads have degraded, and parts of the bead layer have detached. At the edge of the perforatione, remnants of the white bead layer can be observed on the intact end surface of the inner layer. Where the body layer has detached, the inner layer appears rounded and smooth, indicating that the inner layer and body layer were produced sequentially. The probable manufacturing process involved first forming a cylindrical core segment by the core-forming technique and allowing it to dry, followed by coating or immersing the core segment in a bead slurry to form the outer bead layer, and finally drying and firing. Polarized microscopy reveals numerous pores and quartz particles within the bead. SEM-BSE imaging (Fig. 7-6) clearly shows quartz grains with rounded edges, indicating that the bead layer experienced elevated temperatures during firing and reacted with the flux. Lead is locally concentrated in large aggregates within the bead layer, with some occurring as spherical particles. From its distribution, lead is more abundant in the outer bead layer, which is likely associated with weathering processes.

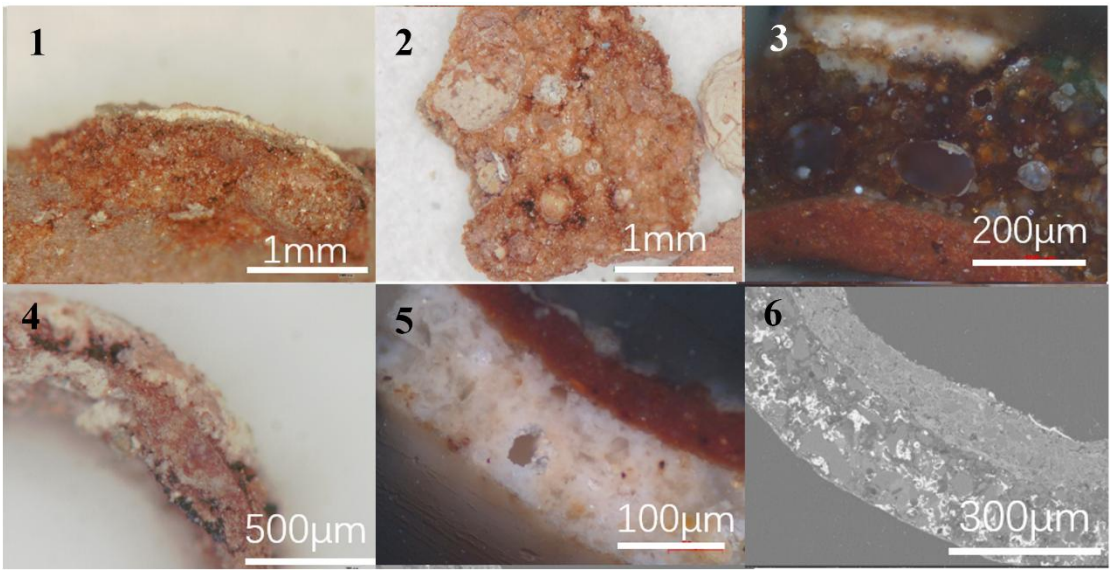


Fig. 7 Microscopic analysis of white beads (1-3: Type A, 4-6: Type B)

The compositional analysis of Type A white faience beads (Tab. 3) indicates that they belong to the PbO–BaO–SiO_2 system. The body contains 50.5% SiO_2, 7.8% BaO, and 30.1% PbO, while Na_2O and K_2O are each below 1% and CaO is 1.8%; CuO was not detected. In the glaze layer, SiO_2 is relatively low at 35.6%, whereas PbO is comparatively high at 50.9%. The glaze also contains 3.5% BaO, 4.9% CuO, and 2.9% Na_2O. SEM elemental mapping reveals co-enrichment of sulfur and lead within the same regions, particularly in the glaze layer, suggesting that the principal component of the glaze may be lead sulfate, with locally preserved large quartz grains. The inner layer exhibits a composition similar to clay, with a relatively high phosphorus content. Lead is present in some areas, which may result from diffusion of lead from the body. Microscopic observations show numerous bubbles at the interface between the inner layer and the body, and large bubbles are also observed within the body. Combined with the compositional data, this suggests that decomposition of barium sulfate likely occurred within the body, generating abundant bubbles.

Type B white faience beads belong to the PbO–SiO_2 system. The bead layer contains 67–73% SiO_2 and 19–24% PbO, with Na_2O below 1.5% and CuO ranging from 2% to 4%. BaO is nearly absent, and MgO and K_2O were not detected. SEM-BSE imaging shows incompletely reacted quartz crystals within the bead layer bonded by a lead-rich glassy phase, and spherical high-lead particles are also observed as residual inclusions. The inner layer contains approximately 62% SiO_2, 3.5–5% Na_2O, about 2.5% K_2O, around 13% Al_2O_3, 2.2% CaO, and approximately 7% Fe_2O_3, with BaO and PbO not detected. This composition is consistent with that of clay materials.

Tab. 3 SEM-EDS composition of white faience beads (wt%)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	Fe_2O_3	CuO	BaO	PbO
GLZ-type A	2.9	0.0	0.0	35.6	0.0	0.8	1.4	0.0	4.9	3.5	50.9
Body-type A	0.9	0.0	4.5	50.5	0.0	0.8	1.8	3.7	0.0	7.8	30.1
Inner Layer-Type A	0.0	1.9	12.4	49.7	7.4	2.3	5.4	6.8	3.2	0.0	11.0
Inner Layer-Type A	3.4	1.7	14.0	57.0	8.1	2.7	3.6	6.3	3.2	0.0	0.0
Body-Type B	1.1	0.0	1.5	73.3	0.0	0.0	0.5	0.0	2.0	0.0	21.6
Body-Type B	1.3	0.0	0.9	75.2	0.0	0.0	0.0	0.0	2.7	0.7	19.2
Body-Type B	1.4	0.0	1.9	67.8	0.0	0.0	0.9	0.0	4.0	0.0	24.1
Inner Layer-Type B	3.8	0.9	13.0	61.8	6.0	3.0	2.2	7.3	1.9	0.0	0.0
Inner Layer-Type B	5.1	1.2	12.5	63.0	5.1	2.3	2.2	6.1	2.7	0.0	0.0

Raman spectra of white beads are shown as Fig.8. The white regions on the surface of the Type A white faience bead sample exhibit Raman peaks at 1052 cm^{-1} and 1304 cm^{-1}, which are largely consistent with the characteristic peaks of $PbCO_3$, indicating that the bead has undergone a certain degree of weathering. For the Type B faience bead, the white body displays Raman peaks at 351 cm^{-1}, 462 cm^{-1}, and 1092 cm^{-1}, corresponding to the characteristic absorption peaks of quartz and $PbCO_3$, suggesting that the bead is primarily composed of quartz and lead carbonate.

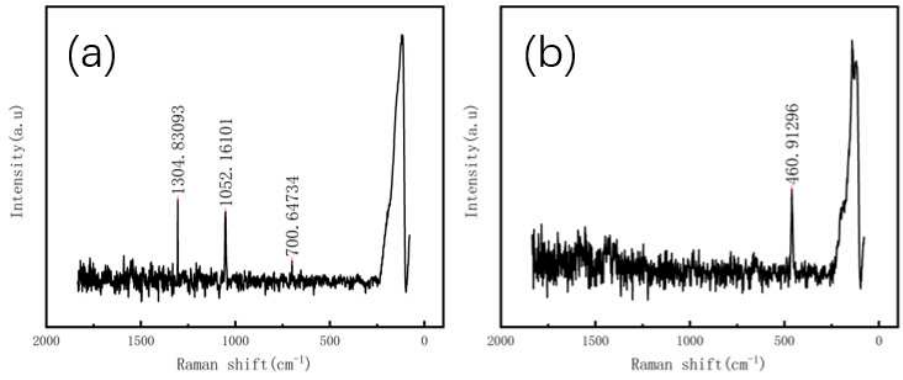


Fig.8 Raman spectrum of white beads (a) Type A bead (b) Type B bead

A Comparative Study of the Composition of Faience Beads Unearthed from M52

To investigate the compositional differences of the silicate beads unearthed from the M52 more intuitively, a bivariate statistical analysis of the sample composition data was conducted by SPSS software. The results, as shown in Fig. 9, indicate that all faience bead samples belong to the lead-barium silicate system. As a distinctive silicate system in China, lead-barium silicate materials were widely prevalent in the Chu region during the Warring States period, exhibiting marked regional characteristics. As early as the Shang and Zhou dynasties, craftsmen utilized lead for its ability to lower melting temperatures and increase fluidity, applying it extensively

in bronze casting. This practice accumulated experience that later facilitated the use of lead ore as a flux in the production of silicate artifacts. As can be observed in the figure, the overall clustering of the faience bead samples from M52 is not particularly pronounced. However, the compositional data for each distinct type of bead displays excellent internal clustering. This suggests that different types of beads were manufactured with their own specific raw material formulas, and possibly even originated from different workshops.

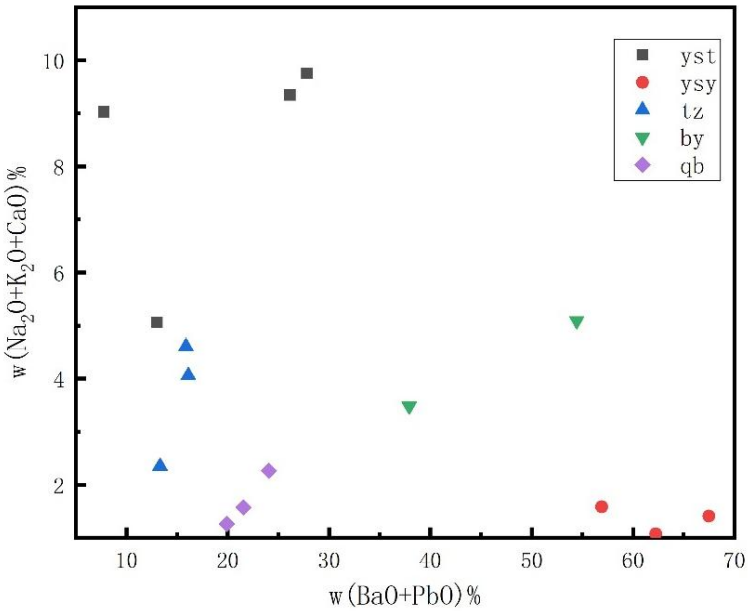


Fig.9 Composition of Faience Beads Unearthed from M52

Yst-BDY of blue beads, Ysy- GLZ of blue beads, TZ- Tubular beads,

By-White beads type A, Qb- White beads type B

Conclusions

The four distinct types of faience beads examined in this study belong to the PbO-BaO-SiO_2 system. They were produced locally in China, with lead oxide and barium oxide, serving as fluxes, derived from two different raw materials. These beads exhibit compositional distribution characteristics similar to those of silicate artifacts unearthed from the M4 at the Majiayuan cemetery, suggesting that the decorative beads may share a common manufacturing origin. All faience beads were formed with the core-forming technique. The tubular faience beads were likely produced by the efflorescence glazing method, with Han blue detected in surface areas; they were strung together with plain-weave textiles. The blue faience beads were manufactured using the direct glazing method. The materials for the body and the glaze layer were prepared separately; after the body was formed, its surface was modified before glazing was applied. Within the body of the Type A white faience beads, a

decomposition reaction of barium sulfate likely occurred, resulting in the formation of numerous bubbles, while the glaze layer consists of lead sulfate. The body of the Type B white faience beads is primarily composed of lead carbonate and silicon dioxide.

Abbreviations

GLZ	Glaze layer
IAL	Interaction layer
OM	Optical microscope
SEM-EDS	Scanning electron microscopy in combination with energy dispersive X-ray analysisX-ray diffraction

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Author contributions

Conceptualization，G. C., H. W. and J. Y.; methodology, Y. X. and L. L.; investigation and data analysis, Y. Z. and A. L.; writing-original draft preparation, L. L. and Y. Z.; writing and editing, L.L and A. L.; supervision, G.C, H. W., J. Y. and Y.X. All authors have given approval to the final version of the manuscript.

Competing Interests

All authors declare no financial or non-financial competing interests.

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